10201

PCT/GB00/03180

924

PATENT COOPERATION TREATY

From the INTERNATIONAL BUREAU

PCT

NOTIFICATION OF ELECTION

(PCT Rule 61.2)

To:

Commissioner
US Department of Commerce
United States Patent and Trademark Office, PCT
2011 South Clark Place Room CP2/5C24
Arlington, VA 22202
ETATS-UNIS D'AMERIQUE

in its capacity as elected Office

Date of mailing (day/month/year) 26 April 2001 (26.04.01)	
International application No. PCT/GB00/03180	**Applicant's or agent's file reference** Job No. 00-07
International filing date (day/month/year) 18 August 2000 (18.08.00)	**Priority date** (day/month/year) 20 August 1999 (20.08.99)
Applicant NEWTON, Timothy	

1. The designated Office is hereby notified of its election made:

   [X] in the demand filed with the International Preliminary Examining Authority on:

   08 March 2001 (08.03.01)

   [ ] in a notice effecting later election filed with the International Bureau on:

2. The election [X] was
   [ ] was not

   made before the expiration of 19 months from the priority date or, where Rule 32 applies, within the time limit under Rule 32.2(b).

The International Bureau of WIPO **34, chemin des Colombettes** **1211 Geneva 20, Switzerland** Facsimile No.: (41-22) 740.14.35	Authorized officer Olivia TEFY Telephone No.: (41-22) 338.83.38

PATENT COOPERATION TREATY

PCT

INTERNATIONAL SEARCH REPORT

(PCT Article 18 and Rules 43 and 44)

Applicant's or agent's file reference Job No. 00-07	**FOR FURTHER ACTION**	see Notification of Transmittal of International Search Report (Form PCT/ISA/220) as well as, where applicable, item 5 below.
International application No. PCT/GB 00/03180	International filing date *(day/month/year)* 18/08/2000	(Earliest) Priority Date *(day/month/year)* 20/08/1999
Applicant SMITH GROUP LIMITED et al.		

This International Search Report has been prepared by this International Searching Authority and is transmitted to the applicant according to Article 18. A copy is being transmitted to the International Bureau.

This International Search Report consists of a total of 4 sheets.

[X] It is also accompanied by a copy of each prior art document cited in this report.

1. **Basis of the report**
   a. With regard to the **language**, the international search was carried out on the basis of the international application in the language in which it was filed, unless otherwise indicated under this item.
      [ ] the international search was carried out on the basis of a translation of the international application furnished to this Authority (Rule 23.1(b)).
   b. With regard to any **nucleotide and/or amino acid sequence** disclosed in the international application, the international search was carried out on the basis of the sequence listing :
      [ ] contained in the international application in written form.
      [ ] filed together with the international application in computer readable form.
      [ ] furnished subsequently to this Authority in written form.
      [ ] furnished subsequently to this Authority in computer readble form.
      [ ] the statement that the subsequently furnished written sequence listing does not go beyond the disclosure in the international application as filed has been furnished.
      [ ] the statement that the information recorded in computer readable form is identical to the written sequence listing has been furnished
2. [ ] **Certain claims were found unsearchable** (See Box I).
3. [ ] **Unity of invention is lacking** (see Box II).
4. With regard to the **title**,
   [ ] the text is approved as submitted by the applicant.
   [X] the text has been established by this Authority to read as follows:

   QAM DEMODULATOR

5. With regard to the **abstract**,
   [ ] the text is approved as submitted by the applicant.
   [X] the text has been established, according to Rule 38.2(b), by this Authority as it appears in Box III. The applicant may, within one month from the date of mailing of this international search report, submit comments to this Authority.
6. The figure of the **drawings** to be published with the abstract is Figure No. 1
   [ ] as suggested by the applicant.
   [X] because the applicant failed to suggest a figure.
   [ ] because this figure better characterizes the invention.
   [ ] None of the figures.

INTERNATIONAL SEARCH REPORT

International application No.
PCT/GB 00/03180

Box III TEXT OF THE ABSTRACT (Continuation of item 5 of the first sheet)

A method of detecting carrier signals of Quadrature Amplitude Modulated (QAM) signals and Phase-Shift Keyed (PSK) signals and demodulators for demodulating QAM and PSK signals. The method uses the times-n technique and makes use of the symmetry in the constellation information. The technique provides carrier phase detection as well as frequency detection. The technique weights down constellation points that provide little information on the carrier frequency.

4

PATENT COOPERATION TREATY

RECEIVED 17 DEC 2001
WIPO PCT

PCT

INTERNATIONAL PRELIMINARY EXAMINATION REPORT

(PCT Article 36 and Rule 70)

Applicant's or agent's file reference Job No. 00-07	**FOR FURTHER ACTION** See Notification of Transmittal of International Preliminary Examination Report (Form PCT/IPEA/416)	
International application No. PCT/GB00/03180	International filing date *(day/month/year)* 18/08/2000	Priority date *(day/month/year)* 20/08/1999
International Patent Classification (IPC) or national classification and IPC H04L27/00		
Applicant SMITH GROUP LIMITED et al.		

1. This international preliminary examination report has been prepared by this International Preliminary Examining Authority and is transmitted to the applicant according to Article 36.

2. This REPORT consists of a total of 9 sheets, including this cover sheet.

   ☒ This report is also accompanied by ANNEXES, i.e. sheets of the description, claims and/or drawings which have been amended and are the basis for this report and/or sheets containing rectifications made before this Authority (see Rule 70.16 and Section 607 of the Administrative Instructions under the PCT).

   These annexes consist of a total of 2 sheets.

3. This report contains indications relating to the following items:

   - I ☒ Basis of the report
   - II ☐ Priority
   - III ☒ Non-establishment of opinion with regard to novelty, inventive step and industrial applicability
   - IV ☐ Lack of unity of invention
   - V ☒ Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations suporting such statement
   - VI ☐ Certain documents cited
   - VII ☒ Certain defects in the international application
   - VIII ☒ Certain observations on the international application

Date of submission of the demand 08/03/2001	Date of completion of this report 13.12.2001
Name and mailing address of the international preliminary examining authority: European Patent Office D-80298 Munich Tel. +49 89 2399 - 0 Tx: 523656 epmu d Fax: +49 89 2399 - 4465	Authorized officer Horbach, C Telephone No. +49 89 2399 7928

I. Basis of the report

1. With regard to the **elements** of the international application *(Replacement sheets which have been furnished to the receiving Office in response to an invitation under Article 14 are referred to in this report as "originally filed" and are not annexed to this report since they do not contain amendments (Rules 70.16 and 70.17))*:

Description, pages:

1-10 as originally filed

Claims, No.:

1-5 as received on 20/11/2001 with letter of 20/11/2001

Drawings, sheets:

1/1 as originally filed

2. With regard to the **language**, all the elements marked above were available or furnished to this Authority in the language in which the international application was filed, unless otherwise indicated under this item.

These elements were available or furnished to this Authority in the following language: , which is:

- ☐ the language of a translation furnished for the purposes of the international search (under Rule 23.1(b)).
- ☐ the language of publication of the international application (under Rule 48.3(b)).
- ☐ the language of a translation furnished for the purposes of international preliminary examination (under Rule 55.2 and/or 55.3).

3. With regard to any **nucleotide and/or amino acid sequence** disclosed in the international application, the international preliminary examination was carried out on the basis of the sequence listing:

- ☐ contained in the international application in written form.
- ☐ filed together with the international application in computer readable form.
- ☐ furnished subsequently to this Authority in written form.
- ☐ furnished subsequently to this Authority in computer readable form.
- ☐ The statement that the subsequently furnished written sequence listing does not go beyond the disclosure in the international application as filed has been furnished.
- ☐ The statement that the information recorded in computer readable form is identical to the written sequence listing has been furnished.

4. The amendments have resulted in the cancellation of:

- ☐ the description, pages:
- ☐ the claims, Nos.:

☐ the drawings, sheets:

5. ☐ This report has been established as if (some of) the amendments had not been made, since they have been considered to go beyond the disclosure as filed (Rule 70.2(c)):

   (Any replacement sheet containing such amendments must be referred to under item 1 and annexed to this report.)

6. Additional observations, if necessary:

III. Non-establishment of opinion with regard to novelty, inventive step and industrial applicability

1. The questions whether the claimed invention appears to be novel, to involve an inventive step (to be non-obvious), or to be industrially applicable have not been examined in respect of:

   ☐ the entire international application.

   ☒ claims Nos. 2.

because:

☐ the said international application, or the said claims Nos. relate to the following subject matter which does not require an international preliminary examination (*specify*):

☒ the description, claims or drawings (*indicate particular elements below*) or said claims Nos. 2 are so unclear that no meaningful opinion could be formed (*specify*):
see separate sheet

☐ the claims, or said claims Nos. are so inadequately supported by the description that no meaningful opinion could be formed.

☐ no international search report has been established for the said claims Nos. .

2. A meaningful international preliminary examination cannot be carried out due to the failure of the nucleotide and/or amino acid sequence listing to comply with the standard provided for in Annex C of the Administrative Instructions:

   ☐ the written form has not been furnished or does not comply with the standard.

   ☐ the computer readable form has not been furnished or does not comply with the standard.

V. Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement

1. Statement

   Novelty (N) Yes: Claims 1,3-5

	No:	Claims	
Inventive step (IS)	Yes:	Claims	1,3-5
	No:	Claims	
Industrial applicability (IA)	Yes:	Claims	1,3-5
	No:	Claims	

2. Citations and explanations
   see separate sheet

VII. Certain defects in the international application

The following defects in the form or contents of the international application have been noted:
see separate sheet

VIII. Certain observations on the international application

The following observations on the clarity of the claims, description, and drawings or on the question whether the claims are fully supported by the description, are made:
see separate sheet

Re Item III

Non-establishment of opinion with regard to novelty, inventive step and industrial applicability

As stated under Re Item VIII, claim 2 is so unclear that no meaningful opinion can be formed on the novelty and inventive step of the claimed subject matter. Consequently, the IPEA will not go into the questions referred to in Article 33(1) PCT concerning the subject-matter of this claim (cf. Article 34(4)(a)(ii) and 34(4)(b) PCT).

Re Item V

Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement

Reference is made to the following documents:

D1: EFSTATHIOU D ET AL: 'A COMPARISON STUDY OF THE ESTIMATION PERIOD OF CARRIER PHASE AND AMPLITUDE GAIN ERROR FOR 16-ARY QAM RAYLEIGH FADED BURST TRANSMISSIONS' PROCEEDINGS OF THE GLOBAL TELECOMMUNICATIONS CONFERENCE (GLOBECOM),US,NEW YORK, IEEE, 28 November 1994, pages 1904-1908
D2: EP-A-0 556 807 (NIPPON ELECTRIC CO) 25 August 1993
D3: EP-A-0 692 896 (PHILIPS) 17 January 1996

1. Considering **method claim 1,** D2 is regarded as closest prior art. D2 discloses a method of detecting a carrier signal within an n-phase-shift keying modulated signal using the steps of
   - multiplication of the phase of the data samples by the factor n (page 6, line 33-39) and
   - the determination of the carrier frequency from the maximum amplitude component of the Fourier transform of the multiplied data samples (page 6, lines 49-58).

   The features added by the invention (cf formulae of steps (d) and (e)) are
   - the generalization of modulation to a quadrature amplitude modulation, the number n being a symmetry factor of the constellation (e.g. 4 for 16-QAM)
   - the multiplication of the data samples with an average phase function $\Phi(r)$ for

the constellation, which only depends on the radius of the data samples, and
- the use of the maximum amplitude component also for determination of the phase of the carrier signal.

It shall be noted at this place that the method steps (a) to (c) of claim 1 appear to describe standard steps of coherent demodulation of a QAM signal and are therefore not considered in the analysis of the inventive step.

The problem to be solved by the present invention may be regarded as extending the method of D2 to QAM modulated signals and to also determine the phase of the carrier signal.

D1 discloses the generation of an average phase function from the received data samples in a similar way as the invention derives an average phase from the constellation points (cf. paragraph 4 in D1). However in D1 this function is only used for determining the carrier phase offset under the assumption that the carrier frequency has been regenerated ideally.

D3 presents a method to weigh the data sample in such a way that only those are taken into consideration for carrier recovery, that are close to a constellation point (page 5, lines 18-24).

The average phase function of the invention presents the features that it is only derived from the constellation and uses only the radius of the data samples. In this way it is possible to use both the phase and the amplitude information of the Fourier transform.

Regarding the available prior art, this solution is not obvious to the person skilled in the art and is therefore new and involves an inventive step (Article 33(1)-(3) PCT).

2. Although referring back to claim 1, **method claim 3** must be regarded as an independent claim, because it defines a method of demodulating whereas claim 1 defines a method of detecting a carrier signal.
   Nevertheless, claim 3 contains all features of claim 1 and as such it also meets the requirements of the PCT with respect to novelty and inventive step (Article 33(1)-(3) PCT).

3. Although referring back to claim 1, **apparatus claim 4** must be regarded as an independent claim, because of the difference in category.
   Nevertheless, claim 4 contains all features of claim 1 and as such it also meets

the requirements of the PCT with respect to novelty and inventive step.

4. Claim 5 is a claim for a demodulator including the features of claim 4 and therefore also meets the requirements of novelty and inventive step (Article 33(1)-(3) PCT).

Re Item VII

Certain defects in the international application

1. Contrary to the requirements of Rule 5.1(a)(ii) PCT, the relevant background art disclosed in documents D1 - D2 is not mentioned in the description, nor are these documents identified therein.

2. In the formula and the legend of step (e) in claim 1 the index of variable φ_p should preferably read d instead of p, because it refers to the phase of a **data sample** and not of a **constellation point** as in the formula of step (d) of the same claim.

3. The description is not in conformity with the claims as required by Rule 5.1(a)(iii) PCT.

4. According to the requirements of Rule 10.2 PCT, the terminology and the signs shall be consistent throughout the application. This requirement is not met in view of the use of the expression "(I)" in lines 2 and 6 on page 8, which apparently refers to the average phase function Φ.

Re Item VIII

Certain observations on the international application

1a. **Claim 2** does not meet the requirements of Article 6 PCT in that the matter for which protection is sought is not clearly defined.
Claim 2 presents an alternative formula for the average phase function $\Phi(r)$ compared to claim 1. One essential element of this formula is the weighting function depending on two arguments and placed between signs for absolute value, i.e. " $| w() |$ ". The claim itself does not give any other detail of the nature of this func-

tion. Furthermore, the function w() in this claim is in contrast to the other parts of the application where the function w() is defined as a real positive function depending on only one argument (claim 1 and lines 10-12 on page 8). As this definition cannot be straightforwardly extended to a function depending on two arguments and possibly with a negative or complex value, the subject-matter of claim 2 is not understandable and is consequently not clear (Article 6 PCT).

1b. The objection as to lack of clarity of claim 2 is corroborated by the fact that the invention according to this claim appears not to be sufficiently disclosed in the application and does therefore not fulfil the requirement of Article 5 PCT.
The introduction a new weighting function w() simply by stating that it now has two arguments is not sufficient to disclose the nature of such a weighting function. The skilled person would not be able to put the formula of claim 2 into practice and could therefore not carry out the invention according to claim 2 (PCT Guidelines II-4.9, Rule 5.1(v) and Article 5 PCT).

1c. Moreover, the formulation of claim 2 as a dependent claim is not clear as it is not a limitation of claim 1; instead one of the features of claim 1 is replaced. Claim 2 should therefore have been formulated as an independent claim (Rule 6.4(b), Article 6 PCT).

2. **Claim 4** is not clear since it does not explicitly include all the essential features of the invention (PCT-Guidelines III-4.4, Article 6 PCT), but instead attempts to rely on a reference to claims of another category to define certain features. Although the reference "according to the method of claim 1 or claim 2" is not objectionable as such, such a reference is interpreted merely as "suitable for carrying out the method"; the claim should therefore have been formulated to be understandable without taking this reference into account, and should have included all the functional definitions corresponding to the method steps of claims 1 or 2.

3. The additional feature of **claim 5**, i.e. the carrier subtraction means, is not clear. The carrier subtraction means and the corresponding paragraph in the description (page 10, lines 14-15) do not explain in an understandable way how subtracting a carrier signal from an incoming modulated signal can result in the modulating signal. The skilled person cannot determine from this wording what kind of

demodulation technique falls under the scope of the claim. Therefore, claim 5 does not meet the requirements of Article 6 PCT that the claims shall clearly define the matter for which protection is sought.

CLAIMS

1. A method of detecting the carrier signal from a QAM signal, comprising the steps of: -

(a) sampling the digital-in-phase binary components I and Q of an incoming QAM modulated signal,

(b) down-converting the components I and Q to a baseband frequency,

(c) scaling the components I and Q so that the I and Q magnitudes are those expected for the constellation,

(d) deriving the average times-n phase by calculating the complex vector Φ where Φ is given by: -

$$\Phi(r) = \frac{\sum_p w(r-r_p)\exp(in\varphi_d)}{\sum_p w(r-r_p)}$$

where p is an index running over symbols in the constellation;
i is the square root of minus 1
r_p is the radius to the constellation point;
φ_p is the phase of the constellation point;
n is the constellation symmetry (4 for four-fold symmetry, e.g., for 16QAM); and
w is a weighting function

(e) determining the frequency and phase of the carrier signal by calculating the maximum amplitude component in the complex Fourier transform F of data from the samples according to the following equation :-

$$F(\omega) = \sum_d W_d \Phi^* (r_d)\exp(in\varphi_p - i\,\omega\, d)$$

where d is an index running over data samples;
r_d is the amplitude of a data sample;
φ_p is the phase of a data sample;
W_d is a (real positive) windowing function (e.g. Hanning);
ω is the normalised angular frequency $= 2\pi f$, where f is the real frequency

2. A method of detecting the carrier signal from a QAM signal according to claim 1, in which the equation in step (d) is replaced by:-

$$\Phi(r) = \frac{\sum_p \int | w(r\cos\phi - I_p, r\sin\phi - Q_p) | \exp(in\phi) r d\phi}{\sum_p \int | w(r\cos\phi - I_p, r\sin\phi - Q_p) | r d\phi}$$

where p is an index running over symbols in the constellation;
i is the square root of minus 1;
I_p is the I component of the pth constellation point;
Q_p is the Q component of the pth constellation point;
ϕ is a phase integration variable;
n is the constellation symmetry (4 for four-fold symmetry, e.g., for 16QAM); and
w is a weighting function.

3. A method of demodulating a QAM signal, including using the carrier detection. method of claim 1 or claim 2 for carrier recovery.

4. A carrier signal detector for detecting the phase and frequency of a carrier signal in QAM signals according to the method of claim 1 or claim 2, including or consisting of sampling means for sampling the digital-in-phase binary components I and Q, down converting means, phase angle measurement means, carrier phase determination means, and carrier frequency determination means.

5. A demodulator for QAM signals according to the method of claim 3, including the carrier signal detector according to claim 4, and QAM signal demodulating means including carrier subtraction means.

(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
1 March 2001 (01.03.2001)

PCT

(10) International Publication Number
WO 01/15400 A2

(51) International Patent Classification[7]: H04L 27/00

(21) International Application Number: PCT/GB00/03180

(22) International Filing Date: 18 August 2000 (18.08.2000)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
9922002.2 20 August 1999 (20.08.1999) GB

(71) Applicant (*for all designated States except US*): SMITH GROUP LIMITED [GB/GB]: Surrey Research Park, Guildford, Surrey GU2 5YP (GB).

(72) Inventor; and
(75) Inventor/Applicant (*for US only*): NEWTON, Timothy [GB/GB]: Smith Group Limited, Surrey Research Park, Guildford, Surrey GU2 5YP (GB).

(74) Agent: LEAMAN, Keith; QED I.P. Services Limited, Dawley Road, Hayes, Middlesex UB3 1HH (GB).

(81) Designated States (*national*): AU, JP, US.

(84) Designated States (*regional*): European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE).

Published:
— *Without international search report and to be republished upon receipt of that report.*

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

(54) Title: DEMODULATOR

$$\Phi(r) = \frac{\Sigma_p w(r-r_p)\exp(in\varphi_p)}{\Sigma_p w(r-r_p)} \qquad (I)$$

(57) Abstract: An apparatus for, and method of detecting a carrier signal of a QAM signal. The method comprises the steps of: (a) sampling the digital-in-phase binary components I and Q of an incoming QAM modulated signal, (b) down-converting the components I and Q to a baseband frequency, (c) scaling the components I and Q so that the I and Q magnitudes are within a range of those expected for the constellation, (d) deriving the average times-n phase for the constellation, (e) determining the phase of the carrier signal, and (f) determining the frequency of the carrier signal by calculating the maximum amplitude component in the complex Fourier transform F of data from the samples. The average times-n phase is derived by calculating the complex vector Φ where Φ is given by formula (I) where is an index running over symbols in the constellation: is the $\sqrt{-1}$; r_p is the radius to the constellation point; ϕ_d is the phase of the constellation point; is the constellation symmetry (For example 4 for four-fold symmetry, e.g., for 16QAM); and, is a smoothing function. The frequency of the carrier signal is calculated according to the following equation $F(\omega)= \Sigma_d W_d \Phi^*(r_d)\exp(in\phi_d - i\omega d)$ is the amplitude of a data sample; Φ_p is the phase of a data sample; W_d is a (real positive) windowing function (e.g. Hanning); ω is angular frequency = 2Πf, where f is the real frequency.

WO 01/15400 A2

10/049924
Rec'd PCT/PTO 20 FEB 2002

I/P RTS

WO 01/15400 PCT/GB00/03180

DEMODULATOR

This invention relates to the detection of carrier signals of Quadrature Amplitude Modulated (QAM) signals and Phase-Shift Keyed (PSK) signals and domodulators for demodulating QAM and PSK signals.

With QAM signals, two carrier signals in phase quadrature are amplitude modulated by a modulating signal and combined for transmission. Each transmitted symbol can thus have a relatively large number of phase and amplitude states, which are generally illustrated as signal points in a signal point "constellation" in a phase plane diagram. The binary components (I and Q) of the two carrier signals are plotted with the values of I along a horizontal axis and the values of Q along an orthogonal vertical axis. PSK signals are restricted set of QAM signals, with constellation points on one or more rings in the phase plane diagram.

Phase shift errors cause the constellation points to rotate through an angle φ from the position where the two carriers are in phase quadrature, and it is customary to use correction algorithms to cancel out the rotation and lock the signal.

Conventional QAM demodulators extract from the combined modulated signal, two binary components I and Q modulated in phase quadrature. The combined modulated signal is generally expressed by $I \cos(2\pi ft) + Q \sin(2\pi ft)$. An oscillator is used to generate two signals in phase quadrature at a frequency close to the anticipated carrier frequency, f, but in phase. The oscillator signals are mixed with the modulated signal to give two channels, I and Q, and an ac component of a frequency twice that of the respective carrier. The ac component is removed leaving two binary signals I and Q.

In order to demodulate the modulated QAM signal, the carrier phase and frequency needs to be accurately determined and extracted from the modulated signal.

All carrier frequency extraction algorithms exploit non-linearity of the modulated signal. Standard techniques are discussed in Webb and Hanzo, "Modem Quadrature Amplitude

Modulation" IEEE Press and Pentech Press, 1994. The main techniques for carrier recovery are:

(a) times-n carrier recovery where the signal is raised to the power of n, and the signal locked to n-times the carrier frequency; and

(b) decision directed carrier recovery - where a decision is made as to the nearest constellation point and the error used to modify the frequency.

Decision-directed feedback can only be used for small frequency errors, (much less than bandwidth/n), as the symbols may be incorrectly determined for larger errors. For the same reason the carrier may not be determined if the signal has poor equalisation.

Times-n recovery does not require the signals to be equalised as well as that for decision-directed recovery. Furthermore, times-n recovery has a much wider capture frequency. However, previously known times-n recovery techniques cannot be applied to arbitrary constellations, and do not make use of the symmetry of constellation points.

The present invention uses the time-n technique but can be applied to arbitrary constellations and makes better use of the symmetry in the constellation information than was possible with previously known times-n recovery techniques. The present invention does not require well-equalised signals and has a wide capture frequency. The technique of the present invention also provides carrier phase detection as well as frequency detection.

In one aspect of the present invention, there is provided a method of detecting a carrier signal of a QAM signal comprising the steps of: -

(a) sampling the digital-in-phase binary components I and Q of an incoming QAM modulated signal,

(b) down-converting the components I and Q to a baseband frequency,

(c) scaling the components I and Q so that the I and Q magnitudes are within a range of those expected for the constellation,

(d) deriving the average times-n phase for the constellation by calculating the complex vector Φ, where Φ is given by: -

$$\Phi(r) = \frac{\Sigma_p w(r-r_p)\exp(in\varphi_p)}{\Sigma_p w(r-r_p)}$$

where p is an index running over symbols in the constellation;

i is the $\sqrt{-1}$

r_p is the radius to the constellation point;

φ_p is the phase of the constellation point;

n is the constellation symmetry (For example 4 for four-fold symmetry, e.g., for 16QAM); and,

w is a smoothing function

(e) determining the phase of the carrier signal, and

(f) determining the frequency of the carrier signal by calculating the maximum amplitude component in the complex Fourier transform F of data from the samples according to the following equation :-

$$F(\omega) = \sum_d W_d \Phi^*(r_d)\exp(in\phi_d - i\omega d)$$

where d is an index running over data samples;

r_d is the amplitude of a data sample;

φ_d is the phase of a data sample;

W_d is a (real positive) windowing function (e.g. Hanning);

ω is angular frequency = $2\Pi f$, where f is the real frequency.

In a further aspect of the present invention, there is provided a method of demodulating a QAM signal comprising the steps of :-

(a) sampling the digital-in-phase binary components I and Q of an incoming QAM modulated signal,

(b) down-converting the components I and Q to a baseband frequency,

(c) scaling the components I and Q so that the I and Q magnitudes are those expected for the constellation,

(d) deriving the average times-n phase for the constellation by calculating the complex vector Φ where Φ is given by:

$$\Phi(r) = \frac{\Sigma_p w(r-r_p)\exp(in\varphi_p)}{\Sigma_p w(r-r_p)}$$

where p is an index running over symbols in the constellation;
r_p is the radius to the constellation point;
φ_p is the phase of the constellation point;
n is the constellation symmetry (for example, 4 for four-fold symmetry, e.g., for 16QAM);
w is a smoothing function

(e) determining the phase of the carrier signal, and

(f) determining the frequency of the carrier signal by calculating the maximum amplitude component in the complex Fourier transform F of data from the samples according to the following equation :-

$$F(\omega) = \sum_d W_d \Phi^*(r_d)\exp(in\phi_d - i\omega d)$$

where
- d is an index running over data samples;
- r_d is the amplitude of a data sample;
- φ_d is the phase of a data sample;
- W_d is a (real positive) windowing function (e.g. Hanning);
- ω is angular frequency = $2\Pi f$, where f is the real frequency;

and,

(g) subtracting the detected carrier signal from the incoming QAM signal to derive the modulating signal in the incoming QAM signal.

In another aspect of the present invention there is provided a carrier signal detector for detecting the phase and frequency of a carrier signal in Quadrature Amplitude Modulated signals, said detector comprising :-

(a) sampling means for sampling the digital-in-phase components I and Q of an incoming QAM modulated signal,

(b) frequency conversion means for down-converting the components I and Q to a baseband frequency,

(c) phase angle measurement means for deriving the average times-n phase operable to calculate the complex vector Φ where Φ is given by:-

$$\Phi(r) = \frac{\sum_p \iint \left|w(r\cos\phi - I_p, r\sin\phi - Q_p)\right| \exp(in\phi) r d\phi}{\sum_p \iint \left|w(r\cos\phi - I_p, r\sin\phi - Q_p)\right| r d\phi}$$

where
- p is an index running over symbols in the constellation;
- i is the $\sqrt{-1}$
- r_p is the radius to the constellation point;
- φ is the phase of the constellation point;

n is the constellation symmetry (for example, 4 for four-fold symmetry, e.g., for 16QAM);

w is a smoothing function:

(d) carrier phase determination means for determining the phase of the carrier signal in the incoming QAM signal, and

(e) frequency determining means for determining the frequency of the carrier signal in the incoming QAM signal by calculating the maximum amplitude component in the complex Fourier transform F of data from the samples according to the following equation:

$$F(\omega) = \sum_{d} W_d \Phi^*(r_d) \exp(in\phi_d - i\omega d)$$

where
- d is an index running over data samples;
- r_d is the amplitude of a data sample;
- ϕ_d is the phase a data sample;
- W_d is a (real positive) windowing function (e.g. Hanning);
- ω is angular frequency = $2\Pi f$ where f is the real frequency.

In another aspect of the present invention there is provided a demodulator for demodulating Quadrature Amplitude Modulated signals, said demodulator comprising :-

(a) sampling means for sampling the digital-in-phase components I and Q of an incoming QAM modulated signal,

(b) frequency conversion means for down-converting the components I and Q to a baseband frequency,

(c) phase angle measurement means for deriving the average times-n phase operable to calculate the complex vector φ where φ is given by :-

$$\Phi(r)=\frac{\sum_p \iint \left| w(r\cos\phi - I_p, r\sin\phi - Q_p) \right| \exp(in\phi) r d\phi}{\sum_p \iint \left| w(r\cos\phi - I_p, r\sin\phi - Q_p) \right| r d\phi}$$

where p is an index running over symbols in the constellation;

r is the radius to the constellation point;

φ is the phase of the constellation point;

n is the constellation symmetry (for example, 4 for four-fold symmetry, e.g., for I6QAM);

w is a smoothing function;

(d) carrier phase determination means for determining the phase of the carrier signal;

(e) frequency determining means for determining the frequency of the carrier signal by calculating the maximum amplitude component in the complex Fourier transform F of data from the samples according to the following equation:

$$F(\omega)=\sum_A W_d \Phi^*(r_d)\exp(in\phi_d - i\omega d)$$

where d is an index running over data samples;

rd is the amplitude of a data sample;

φ_d is the phase of a data sample;

W_d is a (real positive) windowing function (e.g. Hanning);

ω is angular frequency = 2Пf, where f is the real frequency; and

(f) carrier subtraction means for subtracting the detected carrier signal from the incoming QAM signal.

Where there are many constellation points with widely differing phases, the magnitude of (I) is small, otherwise the magnitude is large, and hence those constellation points that provide little information on the carrier frequency will be weighted down.

The phase of (I) is the average times-n phase of the points with that radius. When this is subtracted from the phase of the sample data, this improves the recovery algorithm by removing phase errors for samples with different amplitudes.

Preferably the weighting function (w) is chosen to have a spread comparable to that expected in the data, and zero beyond that. The weighting function may be Gaussian, triangular, or rectangular or other.

The present invention will now be described, by way of an example, with reference to the accompanying drawings, in which:

Figure 1 is a schematic representation of a demodulator constructed in accordance with the present invention.

Referring to Figure 1 the demodulator (10) comprises basically two main components, namely a high performance programmable digital signal processor (11) built around a number of fairly conventional hardware signal processing integrated circuits, and a high power computer 12 comprising two power PC's 13, 14. One of the PC's (13) serves as the controller and the other handles the input and output interfaces.

These two components 11, 12, are coupled, and large RAM buffers are provided to collect snapshots of data which are read by the PC's 13, 14. The PC's 13, 14 are able to upload the required processing parameters to the digital signal-processor 11, and also

provide a remote connection facility *15*, either via a Wide Area Network (WAN) or serial port.

There is a variety of conventional options available for this interface.

Remote access allows full interactive control of the demodulator 10, including retrieval of snapshot data, uploading digital signal processing data, and uploading of the PC's software.

The digital signal processor (11) provides a generic capability for equalisation filtering and demodulation. Within the underlying constraints of the hardware, such as filter lengths and sampling rates, any signal format can be handled. Standard modulation schemes such as 16, 32, 64, 128, 256, 512,1024 QAM and BPSK, QPSK, S-QPSK, 8-PSK can be handled by the demodulator.

The equalisation method used is a 64 complex tap FIR filter operating on samples at twice the symbol rate.

Mounting of collection operations can be very time consuming. However the present demodulator can be used against unknown signal types and can be programmed in the field to cope with almost any signal type.

The demodulator is provided with a screen 16 on which the constellation points of a phase-plane map can be displayed.

In use of the demodulator 10, the incoming modulated QAM signal (at an intermediate frequency, typically of 140MHz, with an input impedance of 50 ohms), is supplied at the input 17 to an analogue front-end unit 18. The front-end unit 18 converts the 140MHz analogue signal to an analogue signal centred approximately at 40MHz. The 40MHz

analogue signal is digitised at a sample rate of 160MHz. and then mixed down to baseband with I and Q channels sampled at 80MHz.

Data are captured from the digitised signal at this point, to identify the approximate symbol rate. The signal is then resampled at twice the symbol clock rate. Data are captured after resampling, and the symbol clock rate is then accurately identified and tracked.

The digitised signal is equalised and decimated by a factor of two to give digital I and Q signals at the symbol rate. These I and Q data are captured and form the input to the carrier recovery which is performed according to the present invention. The detected carrier frequency and phase are used to control a digital mixer, the output of which is passed to a look-up table that translates the I and Q values to the final symbol values. The detected carrier signal is subsequently subtracted from the incoming modulated signal in order to derive the modulating signal of the incoming signal.

CLAIMS

1. A method of detecting a carrier signal of a QAM signal comprising the steps of: -
   (a) sampling the digital-in-phase binary components I and Q of an incoming QAM modulated signal,
   (b) down-converting the components I and Q to a baseband frequency,
   (c) scaling the components I and Q so that the I and Q magnitudes are within a range of those expected for the constellation,
   (d) deriving the average times-n phase for the constellation by calculating the complex vector Φ where Φ is given by: -

$$\Phi(r) = \frac{\Sigma_p w(r-r_p)\exp(in\varphi_p)}{\Sigma_p w(r-r_p)}$$

where p is an index running over symbols in the constellation;
i is the $\sqrt{-1}$
r_p is the radius to the constellation point;
φ_d is the phase of the constellation point;
n is the constellation symmetry (For example 4 for four-fold symmetry, e.g., for 16QAM); and,
w is a smoothing function

   (e) determining the phase of the carrier signal, and
   (f) determining the frequency of the carrier signal by calculating the maximum amplitude component in the complex Fourier transform F of data from the samples

according to the following equation :-

$$F(\omega)=\sum_d W_d \Phi^*(r_d)\exp(in\phi_d - i\omega d)$$

where d is an index running over data samples;

r_d is the amplitude of a data sample;

φ_p is the phase of a data sample;

W_d is a (real positive) windowing function (e.g. Hanning);

ω is angular frequency = 2Πf, where f is the real frequency.

2. A method of demodulating a QAM signal comprising the steps of :-

(a) sampling the digital-in-phase binary components I and Q of an incoming QAM modulated signal,

(b) down-converting the components I and Q to a baseband frequency,

(c) scaling the components I and Q so that the I and Q magnitudes are those expected for the constellation,

(d) deriving the average times-n phase for the constellation by calculating the complex vector Φ where Φ is given by:

$$\Phi(r) = \frac{\Sigma_p w(r-r_p)\exp(in\varphi p)}{\Sigma_p w(r-r_p)}$$

where p is an index running over symbols in the constellation;

r_p is the radius to the constellation point;

φ_p is the phase of the constellation point;

is the constellation symmetry (for example, 4 for four-fold

n symmetry, e.g., for 16QAM);

w is a smoothing function

(e) determining the phase of the carrier signal, and

(f) determining the frequency of the carrier signal by calculating the maximum amplitude component in the complex Fourier transform F of data from the samples according to the following equation :-

$$F(\omega) = \sum_d W_d \Phi^*(r_d) \exp(in\phi_d - i\omega d)$$

where d is an index running over data samples;

r_d is the amplitude of a data sample;

φ_p is the phase of a data sample;

W_d is a (real positive) windowing function (e.g. Hanning);

ω is angular frequency = $2\Pi f$, where f is the real frequency;

and,

(g) subtracting the detected carrier signal from the incoming QAM signal to derive the modulating signal in the incoming QAM signal.

3. A carrier signal detector for detecting the phase and frequency of a carrier signal in Quadrature Amplitude Modulated signals, said detector comprising :-

(a) sampling means for sampling the digital-in-phase components I and Q of an incoming QAM modulated signal,

(b) frequency conversion means for down-converting the components I and Q to a baseband frequency,

(d) phase angle measurement means for deriving the average times-n phase operable to calculate the complex vector Φ where Φ is given by:-

$$\Phi(r) = \frac{\sum_p \iint \left| w(r\cos\phi - I_p, r\sin\phi - Q_p) \right| \exp(in\phi) r d\phi}{\sum_p \iint \left| w(r\cos\phi - I_p, r\sin\phi - Q_p) \right| r d\phi}$$

where p is an index running over symbols in the constellation;

r_p is the radius to the constellation point;

φ_p is the phase of the constellation point;

n is the constellation symmetry (for example, 4 for four-fold symmetry, e.g., for 16QAM);

w is a smoothing function;

(d) carrier phase determination means for determining the phase of the carrier signal in the incoming QAM signal, and

(e) frequency determining means for determining the frequency of the carrier signal in the incoming QAM signal by calculating the maximum amplitude component in the complex Fourier transform F of data from the samples according to the following equation:

$$F(\omega) = \sum_d W_d \Phi^*(r_d)\exp(in\phi_d - i\omega d)$$

where d is an index running over data samples;

r_d is the amplitude of a data sample;

ϕ_d is the phase a data sample;

W_d is a (real positive) windowing function (e.g. Hanning);

ω is angular frequency = $2\Pi f$ where f is the real frequency.

4. A demodulator for demodulating Quadrature Amplitude Modulated signals, said demodulator comprising :-

(a) sampling means for sampling the digital-in-phase components I and Q of an incoming QAM modulated signal,

(b) frequency conversion means for down-converting the components I and Q to a baseband frequency,

(c) phase angle measurement means for deriving the average times-n phase operable to calculate the complex vector φ where φ is given by :-

$$\Phi(r)=\frac{\sum_{p}\iint\left|w(r\cos\phi-I_p,r\sin\phi-Q_p)\right|\exp(in\phi)rd\phi}{\sum_{p}\iint\left|w(r\cos\phi-I_p,r\sin\phi-Q_p)\right|rd\phi}$$

where p is an index running over symbols in the constellation;

is the radius to the constellation point:

φ is the phase of the constellation point;

n is the constellation symmetry (for example, 4 for four-fold symmetry, e.g., for I6QAM);

w is a smoothing function;

(d) carrier phase determination means for determining the phase of the carrier signal.;

(e) frequency determining means for determining the frequency of the carrier signal by calculating the maximum amplitude component in the complex Fourier transform F of data from the samples according to the following equation:

$$F(\omega)=\sum_{d}W_d\Phi^*(r_d)\exp(in\phi_d-i\omega d)$$

where d is an index running over data samples;

r_d is the amplitude of a data sample;

φ_d is the phase a data sample;

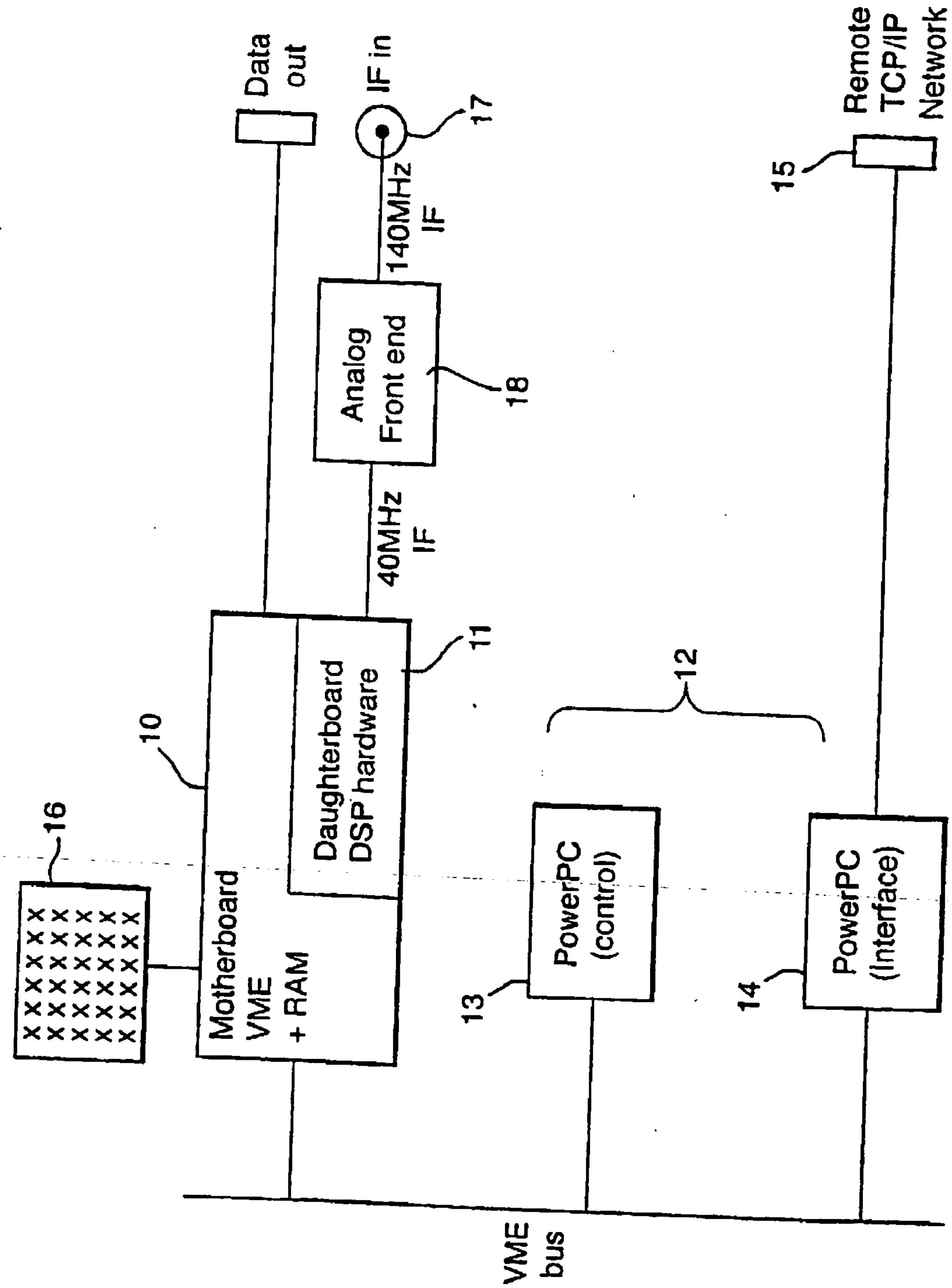
W_d is a (real positive) windowing function (e.g. Hanning);

ω is angular frequency = 2Πf, where f is the real frequency; and

(f) carrier subtraction means for subtracting the detected carrier signal from the incoming QAM signal.

10/049924

WO 01/15400 PCT/GB00/03180



(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

PCT

(43) International Publication Date
1 March 2001 (01.03.2001)

(10) International Publication Number
WO 01/15400 A3

(51) International Patent Classification[7]: H04L 27/38

(21) International Application Number: PCT/GB00/03180

(22) International Filing Date: 18 August 2000 (18.08.2000)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
9922002.2 20 August 1999 (20.08.1999) GB

(71) Applicant *(for all designated States except US)*: SMITH GROUP LIMITED [GB/GB]; Surrey Research Park, Guildford, Surrey GU2 5YP (GB).

(72) Inventor; and
(75) Inventor/Applicant *(for US only)*: NEWTON, Timothy [GB/GB]; Smith Group Limited, Surrey Research Park, Guildford, Surrey GU2 5YP (GB).

(74) Agent: LEAMAN, Keith; QED I.P. Services Limited, Dawley Road, Hayes, Middlesex UB3 1HH (GB).

(81) Designated States *(national)*: AU, JP, US.

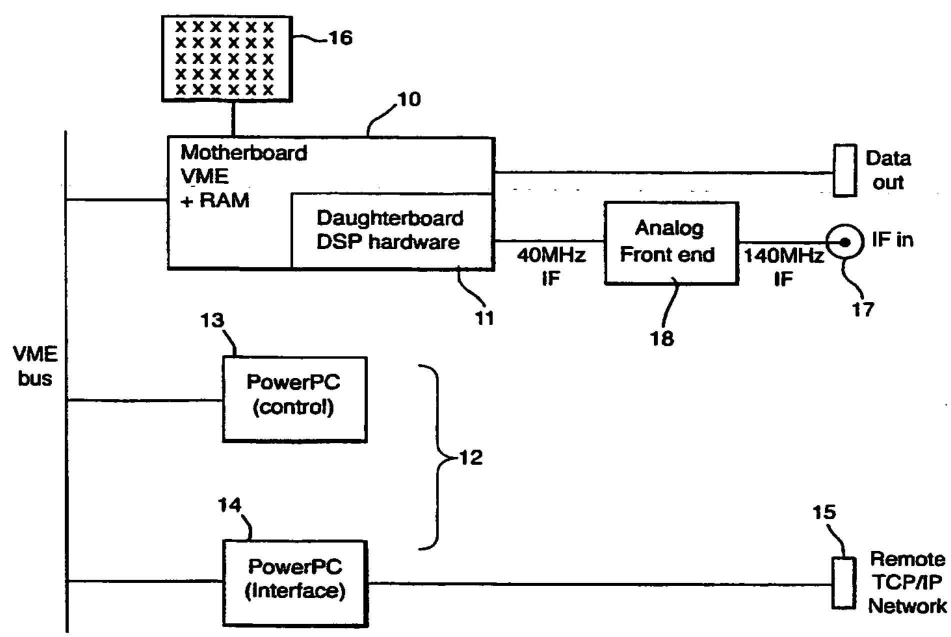
(84) Designated States *(regional)*: European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE).

Published:
— *with international search report*

(88) Date of publication of the international search report: 23 August 2001

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

(54) Title: QAM DEMODULATOR



(57) Abstract: A method of detecting carrier signals of Quadrature Amplitude Modulated (QAM) signals and Phase-Shift Keyed (PSK) signals and demodulators for demodulating QAM and PSK signals. The method uses the times-n technique and makes use of the symmetry in the constellation information. The technique provides carrier phase detection as well as frequency detection. The technique weights down constellation points that provide little information on the carrier frequency.

WO 01/15400 A3

INTERNATIONAL SEARCH REPORT

International Application No
PCT/GB 00/03180

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 H04L27/38

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 H04L

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data, INSPEC, COMPENDEX, PAJ

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	EFSTATHIOU D ET AL: "A COMPARISON STUDY OF THE ESTIMATION PERIOD OF CARRIER PHASE AND AMPLITUDE GAIN ERROR FOR 16-ARY QAM RAYLEIGH FADED BURST TRANSMISSIONS" PROCEEDINGS OF THE GLOBAL TELECOMMUNICATIONS CONFERENCE (GLOBECOM),US,NEW YORK, IEEE, 28 November 1994 (1994-11-28), pages 1904-1908, XP000488851 ISBN: 0-7803-1821-8 section 4 ---	1-4
A	EP 0 556 807 A (NIPPON ELECTRIC CO) 25 August 1993 (1993-08-25) page 6, line 33 - line 58 ---	1-4

-/--

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
6 December 2000	12/12/2000

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Orozco Roura, C

1

INTERNATIONAL SEARCH REPORT

International Application No
PCT/GB 00/03180

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	EP 0 692 896 A (PHILIPS) 17 January 1996 (1996-01-17) page 5, line 18 - line 24	1-4

1

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/GB 00/03180

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
EP 0556807 A	25-08-1993	JP 2812347 B	22-10-1998
		JP 5227235 A	03-09-1993
		AU 659382 B	11-05-1995
		AU 3313793 A	19-08-1993
		CA 2089620 A,C	18-08-1993
		DE 69318201 D	04-06-1998
		DE 69318201 T	17-12-1998
		US 5363415 A	08-11-1994
EP 0692896 A	17-01-1996	FR 2722630 A	19-01-1996
		FR 2733107 A	18-10-1996
		CN 1128923 A	14-08-1996
		JP 8181732 A	12-07-1996
		US 5684842 A	04-11-1997